
Kai-guang ZHANG, Ming-ting BA, Yan-min SUN and Hong-ling MENG
Zhengzhou Normal University, Zhengzhou 450044, China
*Corresponding author

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Abstract. A new accessibility index is designed by using the resident population weighted average value of the inverse of the traveling time distance to analyze the spatial-temporal characteristics of Henan city accessibilities and its evolution patterns from 2004 to 2016. The results show that as the expanding and perfecting of Henan highway traffic network, the city accessibility levels have been effectively improved, and produced obvious spatial convergence effect. The spatial distribution pattern of city accessibilities show more significant trend with time, the city accessibility levels gradually weaken along the northwest-southeast direction, are relatively balanced on the east-west direction. The evolution characteristics have obviously differences in the different years. The optimization degree in 2004-2008 is obviously higher than that of in 2008-2016. The degrees of improvement of the periphery cities are always higher than that of the other cities, the overall standard deviation gradually becomes larger. There is some non-coordination behaviors are appearing between the growth rates of the highway mileage and the growth rates of the city accessibility. The aggregation characteristics of city accessibility are gradually weakening, the aggregation area gradually decreases. The spatial distribution of city accessibilities and population gradually tend to be harmonious.

Introduction

Highway traffic system is an important symbol of transportation modernization, forming a regional vascular and lifeline. An excellent highway system can not only effectively improve the regional logistics levels, shorten the distance between cities, but also provide the fundamental guarantee for regional economic balanced development and promoting regional economic integration[1,2]. Therefore, the evolving pattern research of regional highway traffic system is of great significance to appraise the status and tendencies of regional economic development. In modern location theory, Accessibility index is an important index to evaluate the improvement degree of a traffic network, which mainly describes the size of each node's interaction opportunity and the convenience of traffic among nodes in the traffic network [3,4].

At present, the accessibility studies mainly concentrate on the accessibility distribution status, the spatial distribution and evolution characteristics, the impact on regional economic development, at the same time, introduce the fractal theory, network theory, syntax, shortest path and spatial topology to structure accessibility factors reflecting the different network characteristics, and obtain some valuable results [5-17]. But the research object is mainly for simple traffic network, the research measure use Euclidean distance, the changes of measure values are seriously affect the reliability of the analysis results.

Henan Province is the main body of the Central Plains Economic Zone, is one of China's important transportation hub. By the end of 2015, a basic sound highway traffic network in the province with 9 vertical and 12 horizontal national highways, and a number of provincial highways has been forming, which provides the basic guarantee for regional economic development [18].

Based on Henan general traffic network to define the traveling time thresholds, the paper designs a new accessibility index by using the inverse of traveling time distance with population weighted in the highway traffic network, to evaluate the temporal and spatial evolution characteristics of city
accessibility, and to explore the spatial relationship between city accessibility and city population change. The new accessibility index could effectively reduce the numerical effect of the measure data on the analysis results, and make the analysis more reflect the reality of the basic situation [19].

Data and Research Methods

Data

The operation of the first highway line, Lankao to Luoyang section of Lianhuo national highways, marked the Henan transportation is run into high-speed traffic era. Since 2004, along with the province's economic strength has grown, the province's highway network has been rapid developed, by the end of 2015, the highway mileage is up to 6600 km, basically formed a sound highway traffic network with 9 vertical and 12 horizontal national highways as the framework. This paper evenly divided the 12 years (early 2004 - early 2016) into 3 time stages, and 4 time sections to study the impact of highway constructions on city accessibility, in order to explore the Spatial-temporal characteristics and evolution patterns of city accessibilities, as well as the spatial relationship between city accessibility and city population change.

The spatial data of the study are from the Henan highway spatial database and meta-database. The time distance is based on the weighted average of the empirical traveling time on lines and intersections from the corresponding years. The shortest distance between cities is calculated by NEDS algorithm [20]. The resident population data are from the Henan Province Statistical Yearbook.

Accessibility Index

The city accessibility index is a description of the traffic convenience degree from all adjacent cities to the city. There are various possibilities in direct connections and circuitous connections between two adjacent cities in the highway traffic network. The study of city accessibility coming from highway traffic network only use the traffic routes within the time threshold defined before, usually the time threshold is set as the shortest travel time between cities on the ordinary traffic network. Two routes are considered to be the same if and only if their route repetition rate is greater than 50%.

The resident population weighted average of the inverse of time distance is used to calculate the city accessibility level, the use of the inverse could greatly reduces the influence of numerical value on the analysis results.

The city $i$ accessibility from city $j$ is defined as the sum of the inverse of time distance from city $j$ to city $i$ for all routes, on which the traveling time are less than the time threshold, and do not travel through the third city, denoted as $A_i$, the larger $A_i$ means better traffic convenience degree from city $j$ to city $i$, sometimes $A_i \neq A_j$.

The city $i$ accessibility $A_i$ is defined as the resident population weighted average of accessibility from all adjacent cities in the region,

$$A_i = \sum_{j \neq i} \frac{M_j A_j}{M_j},$$

where, $M_j$ is the resident population of the city $j$ indicating the influence degree of $j$ on the other city accessibilities. The larger $A_i$ means the better traffic convenience degree from all adjacent cities to city $i$.

Spatial Auto-correlation Analysis

The spatial auto-correlation analysis is based on Moran I index, which describes the spatial correlation patterns at different spatial positions, reflects the spatial difference and similarity degrees for the adjacent regions with a certain regular distribution samples.
\[ I_i = (x_i - \bar{x}) \sum_{j=1}^{n} w_{ij} (x_j - \bar{x}) / s^2 \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \]  \tag{2}

where, \( x_i, \bar{x}, s \) respectively are the sample value, the mean and the variance. The test statistics, normalizing \( z \), describes the aggregation degree between the regional samples.

**Centrality Analysis**

The city accessibility, coming from highway traffic system is closely related to its location in the network and weighting parameters, reflects the location centrality of the city in the regional traffic network and the convenience of population circulation.

The accessibility center \( B_i \) in the region is defined as the accessibility weighted average of city geographical coordinates, and the population center \( R_i \) is defined as the resident population weighted average of city geographic coordinates.

\[ B_i = \frac{\sum A_i x_i}{\sum A_i} \]  \tag{3}

\[ R_i = \frac{\sum m_i x_i}{\sum m_i} \]  \tag{4}

where \((x_i, y_i)\) represents the geographical coordinates of the city \(i\).

**Spatial-Temporal Characteristics of the City Accessibilities in Henan Province**

**Spatial-Temporal Evolution of Highway Traffic Network in Henan Province**

Henan highway traffic network has got considerable development in the 12 years from 2004 to 2016, the highway mileage has increased from 680 km in 2004 to 6600 in 2016, which has increased nearly 10 times, of which the first stage is the fastest growing stage to reach 464%, followed by the second stage as 33%, and the third stage as 28%. The 2.5h city traffic circle with Zhengzhou as the center has been forming in the region.

**Spatial Patterns of City Accessibilities in Henan Province**

The city accessibilities on each time section in Henan Province are calculated by using (1), and the corresponding time thresholds and the resident population data. The results are shown in Table 1. For each time section, using spatial clustering analysis, divided the city accessibilities into 4 groups, in accordance with the good difference in four grades, the results are showed in Figure 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>ZZ</th>
<th>KF</th>
<th>LY</th>
<th>PDS</th>
<th>AY</th>
<th>HB</th>
<th>XX</th>
<th>JZ</th>
<th>PY</th>
<th>XC</th>
<th>LH</th>
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<td>0.98</td>
<td>0.74</td>
<td>0.41</td>
<td>0.53</td>
<td>0.63</td>
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<td>1.08</td>
<td>0.33</td>
<td>0.43</td>
<td>0.53</td>
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<td>1.40</td>
<td>1.52</td>
<td>1.77</td>
<td>0.69</td>
<td>1.25</td>
<td>1.61</td>
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<tr>
<td>2012</td>
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<td>1.65</td>
<td>1.06</td>
<td>1.04</td>
<td>1.21</td>
<td>1.66</td>
<td>1.57</td>
<td>1.79</td>
<td>0.87</td>
<td>1.40</td>
<td>1.59</td>
</tr>
<tr>
<td>2016</td>
<td>1.60</td>
<td>2.10</td>
<td>1.31</td>
<td>1.09</td>
<td>2.25</td>
<td>2.30</td>
<td>1.63</td>
<td>2.06</td>
<td>1.02</td>
<td>1.59</td>
<td>1.82</td>
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<tr>
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<th>NY</th>
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<th>ZK</th>
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<th>Z</th>
</tr>
</thead>
<tbody>
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<td>0.21</td>
<td>0.46</td>
<td>0.43</td>
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<td>0.42</td>
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<td>0.38</td>
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<td>2008</td>
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<td>0.69</td>
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<td>0.77</td>
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<tr>
<td>2012</td>
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<td>0.74</td>
<td>1.23</td>
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<td>1.28</td>
<td>0.40</td>
<td>0.31</td>
<td>2.08</td>
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<tr>
<td>2016</td>
<td>0.88</td>
<td>0.74</td>
<td>1.30</td>
<td>0.78</td>
<td>1.40</td>
<td>1.07</td>
<td>2.19</td>
<td>1.51</td>
<td>0.52</td>
<td>0.21</td>
<td>1.61</td>
</tr>
</tbody>
</table>
On four time sections, Jiaozuo and Kaifeng accessibilities are always in the excellent group, they are tourism-oriented cities, in order to attract tourists, the local governments increase the construction of transport facilities, have completed a number of highway construction in the different time stages, constitute a radioactive traffic network.

On the first two time sections, Zhengzhou accessibilities are in the excellent group, and on the latter two time sections are in the good group, that is for the city accessibility level not only reflects the distribution of highway traffic network in the city region, but also is affected by its spatial geographical position in the highway traffic network and the city resident population of its adjacent cities. The operations of Zhengyao highway in 2009 and Jixi highway in 2015 make the direct linkage range respectively extend to Pingdingshan and Zhoukou.

On four time sections, Sanmenxia, Nanyang, Xinyang and Puyang always have poor accessibility levels, their common features are located on the periphery of the province, have relatively complex terrain and low population density.

In the spatial distribution, the city accessibilities show HH and LL aggregation characteristics, Moran I coefficients and significant levels gradually reduce (Figure 2). Xinxiang always is of HH aggregation area on the four time sections. On the first three sections, Zhengzhou is of HH aggregation area, but on the fourth section, the HH aggregation characteristics are not obvious. Puyang, the north-eastern city, shows LL aggregation characteristics on the fourth section.

**Spatial Patterns of City Accessibilities in Henan Province**

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**The Evolution Pattern of City Accessibilities in Henan Province**

On the first two time sections, the city accessibilities show the core-periphery feature centered on the provincial capital Zhengzhou, gradually weaken along the northwest-southeast direction, but the distributions are relatively balanced on the east-west direction. On the last two time sections, the core characteristics gradually trend to be weakness, the city accessibilities in the northern cities are higher than that of southern cities, the city accessibilities decreases from north to south.

On the whole, the accessibility levels of each city in the province have been improved to a certain extent on the four time sections, the mean values have increased from 0.56 to 1.51, but the standard deviation gradually become larger(Figure 3). Some non-coordination behaviors are appearing between the growth rates of the highway mileage and the growth rates of the city accessibility. All of these indicate that the highway traffic network construction in the province has been rapid development, but the network layout differences are enlarging.

**The Evolution Pattern of City Accessibility Centers in Henan Province**

Using (3) and (4) to calculate the city accessibility centers and resident population centers at each time section, the results are showed in Figure 4 Figure 5. With the development of urbanization, the population agglomeration in Zhengzhou is becoming more and more obvious. The resident population center is continuously moving to the northwest. But during the three stages, the aggregation speed gradually decreases.

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There are significant differences between the trend of city accessibility centers and the trend of resident population centers. In the first stage, the rapid development of the highway traffic network in the central and southern regions makes the city accessibility center move 15 km to the southeast. In the second and the third stages, due to lots of provincial highway construction in the central and northern regions, the city accessibility center gradually move to Zhengzhou along the northwest direction, the moving speed is significantly faster in the third stage than that in the second stage.

The distance between the city accessibility center and the resident population center is gradually reduced, which indicates that the highway construction in the province is effective in promoting the process of population circulation and urbanization while improving the urban accessibility level on the one hand, and on the other hand also shows that the province's highway network layout gradually tends to rationalize.

Conclusion

The using the resident population weighted average value of the inverse of the traveling time distance and the time threshold coming from ordinary traffic network to research the city accessibility could effectively reduce the numerical effect of the measurement data on the analysis result, and make the analysis results more reflect the basic situation of reality.

As the expanding and perfecting of Henan highway traffic network, the city accessibility levels have been effectively improved, and produced obvious spatial convergence effect. The spatial distribution pattern of city accessibilities show more significant trend with time, the city accessibility levels gradually weaken along the northwest-southeast direction, are relatively balanced on the east-west direction.

Since the construction of highway traffic network has the stage characteristics, the evolution characteristics of city accessibilities have obviously differences in the different stages. The optimization degree of city accessibilities in the first stage is obviously higher than that of in the second and third stages. The degrees of improvement of the periphery cities are always higher than that of the other cities, the overall standard deviation gradually becomes larger. There is some non-coordination behaviors are appearing between the growth rates of the highway mileage and the growth rates of the city accessibility.

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References


